PATENT SPECIFICATION

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DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in Electric-Arc Steelmaking

We, METALLGESELLSCHAFT AKTIENGESELLSCHAFT, a joint stock Company organised under the Laws of Germany, of 14, Reuterweg, Frankfurt, Main, Germany, THE STEEL COMPANY OF CANADA LIMITED, a Company organised under the Laws of Canada, of Wilcox Street, Hamilton, Ontario, Canada and PICKANDS MATHER & CO., a Corporation organised under the Laws of the State of Delaware United States of America, of 2000 Union Commerce Building, Cleveland, Ohio, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to electric arc steelmaking and is particularly directed to a method of continuously charging iron-bearing material into an electric arc steelmaking furnace.

Conventional electric arc steelmaking furnaces, such as the Heroult direct-arc type, utilize scrap metal as melting stock which is top-charged or door-charged into the furnace. The charging of scrap materials into the furnace necessitates, in addition to the initial furnace charge, from two to as many as six scrap recharges in order to obtain the desired final metal charge weight in the furnace, the number of recharges required depending upon the size and shape of the scrap used. Prior to each recharging of the furnace with scrap, the power is shut off, the hot electrodes withdrawn and, in a modern top charged furnace, the roof lifted and swung to one side. The scrap charge is then placed in the furnace by means of a drop-bottom bucket or the like which is brought to the open furnace and held in position over it by an overhead crane, this method of charging scrap to the furnace heretofore having been considered to be the quickest and most efficient technique available. The time taken to complete a recharge of scrap varies, a charging time of from 4 to 7 minutes being normal for a modern steelmaking furnace. It is evident that elimination of these interruptions for recharging from the steelmaking sequence would result not only in shorter heat times but also in reduced energy consumption per ton of steel produced since considerable heat lost from the furnace chamber by radiation when it is opened to receive a scrap charge must be subsequently recovered.

In electric-arc steelmaking furnaces, the electric current passes through one electrode, across the arc created between the foot of the electrode and the scrap or bath, then through the scrap or bath and up across another arc to an adjacent electrode, completing the circuit through this second electrode. The arcs constitute a variable resistance in the circuit which can be altered by raising or lowering the electrodes to change the arc length, the electrodes being moved up and down by automatic means which seek a predetermined position and therefore correct resistance to maintain the electric current and applied voltage at the value chosen by the furnace operator. Because the scrap tends to fall against the electrodes as the electrodes bore through the scrap charge, the arcs are frequently short-circuited, resulting during the meltdown period, in effect, in a series of short circuits; *i.e.* one or more of the three phases of the furnace transformer secondary circuit is short circuited. Arc energy interruptions resulting from these short circuits normally are brief in duration being in the order of a few seconds. However, interruptions as long as 30 seconds sometimes occur if the electrode is short-circuited by scrap falling against it at a point some distance above the foot of the electrode necessitating pulling the electrode out of the bore cavity to a point just above scrap before effective power can be resumed. It is clear that elimination of these frequent power inter-

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ruptions by stabilizing the arc during the meltdown period of steelmaking would result in employment of a higher average electrical energy input and realization of a shorter heat time.

Conventional electric-arc furnaces furnish most of the heat for melting scrap by means of a direct-arc formed between each electrode and scrap material.

The electric-arc provides a very intense source of high temperature heat (6300°F. for the carbon arc), heat being radiated from along the length of the arc and generated at the interfaces of arc/metal or slag, and arc/electrode. These locations of high temperature referred to herein as the "arc flare zones" normally occupy positions at the foot of each electrode flaring away from the edge opposite to the furnace centre toward the wall of the furnace and arcing downwardly to the bath. The rate at which a given charge will absorb the heat from the three arc flare zones is largely dependent upon the area of cold metal exposed to the radiation from these zones, the rate of heat transfer diminishing continuously as the average temperature of the scrap charge rises. After meltdown, the energy dissipated by the arc zones must be decreased in order to protect the refractory side walls and roof in line of sight of the arcs from overheating. It is clear that the presence of means or a method of protecting the furnace refractories would permit full power utilization at all times during steelmaking with resulting shortened heat times, *i.e.* the time to make one batch (heat) of steel.

The steelmaking cycle consists of five operations: the "meltdown period" when the scrap is melted; "refining period" when the impurities of the molten steel bath are removed and alloying and deoxidizing additions are made; "tapping period" when all of the molten charge is removed from the furnace chamber; "fettling period" when the furnace bottom and banks are repaired in preparation for the next heat; and "charging period" when the scrap metal is placed in the furnace. Of these operations, the refining period can be the most variable, the length of the refining period depending upon the composition of the metal bath on completion of the meltdown of the scrap. In that scrap is a heterogeneous material of variable and of times unknown chemical composition, having been collected from a multiplicity of sources, the composition of the melt bath at meltdown usually cannot be predicted with a reasonable degree of accuracy. For example, it is often found that the sulphur or phosphorus content of the metal at meltdown exceeds the amount specified for the finished steel. In such cases, a lengthy steelmaking procedure known as the two-slag practice may be necessary to lower the content of these elements. This practice consists of shutting off the power, raising the electrodes, back-tilting the furnace slightly, and then raking the slag off the metal pool through the charging door using a rabble. A second slag is then made up by charging for example lime, powdered coke, fluorspar and sand to the furnace. This procedure can take from 20 to 60 minutes. It is also usually found that the carbon content of the bath after melt down is either too high or too low for the grade of steel specified. The carbon content is decreased in the refining period by making additions of iron ore or mill scale or by lancing the bath with gaseous oxygen. The carbon content is increased by making additions of coke, coal or graphite to the bath. Dipping the graphite electrodes in the bath is sometimes used although this is an expensive method of recarburizing the bath. The temperature of the steel prior to tapping must fall within a narrow specified temperature range somewhat above the liquidus temperature of the steel, particularly if the molten steel is to be continuously cast. It is evident that elimination or shortening of this prolonged period of bath composition and temperature adjustment would constitute a very significant improvement in electric-arc steelmaking.

In addition to charging scrap metal to an electric-arc steelmaking furnace, sponge iron has been used, in most cases, with poor results; *i.e.* longer heat times and higher power consumptions being necessitated. The reason for this is as follows: At the start of meltdown, the electrodes first cause the scrap immediately below the electrodes to melt with the result that this molten metal in flowing downwardly freezes on the cooler scrap lower in the furnace. As more and more scrap is melted, a pool of metal collects on the bottom of the furnace and the whole charge then seems to melt from the bottom up. With a sponge iron charge, the melting sequence becomes more difficult in that sponge iron particles, probably due to the presence of low temperature gangue components, tend to weld together under the application of heat forming an impermeable and difficult to melt cluster. Due to the small, uniform size of sponge iron particles, and in particular sponge iron pellets, these materials pack tightly together when charged to the electric-arc furnace. The heat in the furnace from either the molten metal or the hot electrodes causes the outer layers of the sponge iron pile in the furnace to fuse, sealing off and effectively insulating the sponge iron in the interior of the pile from receiving heat directly. Since sponge iron is a poor heat conductor, the fused pile or cluster melts slowly. It is evident that a method for eliminating the formation of sponge iron clusters would permit effective utilization of sponge iron in the electric-arc furnace. Sponge iron is a preferred alternative to scrap in that it has a known and relatively consistent chemical composition.

In many direct reduction processing plants,

a considerable portion of the sponge iron produced is finer than 3/16 inches and, in some of these plants, the entire output is very much finer than this size. When such fine sponge iron is charged to an electric arc steelmaking furnace difficulty is experienced in melting down the charge, particularly when the fine material constitutes more than 20 per cent of the charge in that the metallic fines tend to form a closely packed layer of very high density in the furnace. During the meltdown this layer acts as a barrier to the molten metal and slag formed under the descending electrodes with the result that, according to conventional practice, an adverse melting condition is created; *i.e.* melting of the charge from the top to bottom. In this situation, the arcs are exposed to the roof and to the upper courses of the side wall bricks with resultant damage to the affected refractories. Also, under this situation, the fines tend to fuse firmly together forming a very difficult to melt mass or cluster necessitating, as a result, a prolonged meltdown period with attendant higher than normal energy consumption.

Another disadvantage of fine material is the reduced yield that can result from its use. Some of the fine metallic material dropped into the furnace in the recharges tend to float on the slag surface and if a slag flushing operation is performed at this time, the floating metal may leave the furnace via the slag with a consequent serious decrease in metallic yield. To overcome the above disadvantages, it has been conventional practice to cold or hot press the metallic fines into dense briquettes having a suitable size and shape. Briquettes give no problems in melting. Although briquetting represents a solution to the problem of employing fines in steelmaking, it also represents additional cost both of capital to purchase a briquetting press and of operation to power, maintain and to man the press. A steelmaking procedure whereby metallic fines could be used directly in the furnace without a decrease in productivity and an increase in energy consumption is desirable in obviating these capital costs.

Many techniques have been devised and attempted over the years to improve the operation of electric-arc steelmaking furnaces including the charging of sponge iron into the furnace through holes provided in the furnace roof. Heretofore such techniques have not led to significant improvement in the steelmaking operation, and, therefore, such methods have not met with ready acceptance and commercial use. For example, German Patent No. 954,699, issued December 20, 1956, describes an apparatus for charging materials to an electric-arc steelmaking furnace, but does not give sufficient operating instructions to enable a steelmaker to carry out a process of concurrently charging, melting and refining the iron-bearing feed. Nor does the patent teach the optimum location of feeding iron-bearing material. For another example, United States Patent No. 3,153,588, issued October 20, 1964 teaches a technique for the feeding of sponge iron into an electric-arc steelmaking furnace. According to this patent, an essential part of the operation is that "the arc should be covered by sponge iron and, therefore, the arc submerged in the sponge iron". As mentioned previously, this practice leads to the formation of clusters which are difficult to melt and which result in a condition of continuous electrical shorting of the electrode. Accordingly, the teachings of this patent are contrary to the process of the present invention which is found economically operative as will be described and claimed hereinbelow.

According to the invention there is provided a method of producing steel containing from 0.02 to 1.8% carbon from materials containing metallic iron, in an electric arc furnace, comprising forming a metal pool with a layer of slag thereabove in the furnace, and then continuously introducing iron-bearing material in small particulate form, into the layer of slag above the metal pool at a rate controlled by reference to the electrical power consumption of the furnace such that at the end of the introduction of the iron-bearing material the metal melt is substantially at the temperature required for tapping the furnace and possesses the desired carbon content.

Throughout the specification, figures relating to oxygen refer to residual oxygen molecularly combined with the iron. The initial charge of the electric furnace includes in addition to the metal and iron-bearing material the necessary fluxing, carbon and alloying additives. It is not necessary that the discrete particles be present in the initial charge and, accordingly, the charge may initially be made up with only scrap metal.

After the furnace is charged, the electrodes are positioned in proximity to the charge and power is applied to direct arcs from the electrodes to the charge to form bore cavities which consolidate therein to form a trefoil-shaped pool of molten metal having a slag layer. The discrete particles of iron-bearing material are then continuously fed into the said pool at locations of the flare zones while the power is continuously applied to simultaneously melt and refine the charge. This continues until the entire charge is melted and refined, the discrete particles normally constituting up to about 82 per cent of the total metal charged and in some cases constituting up to 100 per cent of the total metal charged. The refined steel is then tapped from the furnace before the total energy consumption exceeds about 700 kilowatt hours per ton of the refined steel. Thus, the steel is refined as it is melted and while the continuous charging occurs so that no extended refining time at the end of the charging cycle is required

and no power interruptions or temperature recovery times are necessary, thereby ensuring that the total energy consumption can be held below 700 kilowatt hours per ton even though up to about 12 per cent of the iron compounds have not been reduced to the metallized state.

The term "steelmaking", where used herein, is intended to include making an iron-carbon alloy where the carbon is in the approximate range of from 0.02 per cent to 1.8 per cent and the other constituents are in a refined state.

Preferably the particulate iron bearing material has a particle size of less than 3/16 inch, more preferably less than 1/16 inch, and is present in amounts of up to about 80 per cent of the charge.

Discrete particles of iron-bearing material may be utilized such as sponge iron having a known composition within the approximate range of 76 per cent to 99.5 per cent by weight total iron having a residual oxygen content of from 0.1 per cent to 1.75 per cent together with scrap iron and/or scrap steel, if desired, for the production of steel of predetermined composition.

The discrete particles of particulate iron bearing material are preferably continuously fed in after initial charge melting is substantially complete.

A specific embodiment of the invention will now be described by way of example, with reference to the accompanying drawings in which:—

Figure 1 is a perspective view, partly cut away, of a three-phase electric-arc furnace of the type employed in the present invention;

Figure 2 is a plan section taken along the line 2—2 of Figure 1 showing the formation of bore cavities consolidated into a trefoil-shaped pool within the furnace;

Figure 3 is an enlarged vertical section taken along the line 3—3 of Figure 2 showing the introduction of sponge iron in proximity to an electrode;

Figure 4 is a schematic illustration, in part, of the furnace illustrated in Figure 1 showing the charging system for continuous feeding of sponge iron to an open bath in the furnace;

Figure 5 is a flowsheet of a steelmaking system using the method of the present invention;

Figure 6 is a graphical illustration of charge weight and power input relative to heat time for conventional electric steelmaking practice utilizing scrap material showing meltdown and refining periods;

Figure 7 is a graphical illustration of charge weight and power input relative to heat time for the method of the invention utilizing controlled continuous charging of sponge iron pellets showing meltdown and holding periods; and

Figure 8 is a graphical illustration of the affect of residual oxygen on furnace productivity.

Like reference characters refer to like parts throughout the description of the drawings.

With particular reference to Figures 1 and 4, and embodiment of the structure of the present invention will now be described wherein furnace 10 has cylindrical side wall 12 with removable roof 14 secured to arms 16 extending from mast 18. Arms 16 are adapted to be raised and lowered above the side wall 12 by a hydraulic or mechanical system, not shown, formed in mast 18. Three electrodes 24, 26 and 28 are each mounted on masts 29, 30 and 31 by means of arms 32, 34 and 36 for independently raising and lowering each of said electrodes through openings formed in roof 14 equispaced about the roof centre. Masts 18 and 29—31, in turn, are supported by platform 20 having rollers 22 for pivoting said platform abut its axis, thereby moving roof 14 and electrodes 24, 26 and 28 to one side of furnace 10 for loading with scrap material and the like charge materials.

Three conduits 40, 42 and 44 having telescopic extensions 41, 43 and 45 retractable from and extensible into sleeves 46 formed in stationary ducts 48, 50 and 52 are in communication with openings formed in the furnace roof 14 at points between electrodes 24, 26 and 28 respectively and furnace side wall 12. Said conduits, sloping at an angle greater than the angle of repose of the material charged, in this embodiment sloping at an angle of about 40° to the horizontal, are in communication at their upper extremities with a conventional splitter box 56 having gating means for independently regulating the flow of material to each conduit. Mechanical, or pneumatic or hydraulic piston-cylinder units 58 permit the extension and retraction of conduit extensions 41, 43 and 45 to and from their respective sleeve engaging positions. Bucket elevator 49 which receives sponge iron at a controlled rate from weight feeder 51 in communication with hopper 53 continuously feeds splitter box 56.

In operation, roof 14 and electrodes 24, 26 and 28 are lifted and swung away from the furnace 10 for charging to the furnace of scrap iron and/or scrap steel together with fluxing, alloying and carburizing additives, if desired, and said roof and electrodes then returned to their respective operative positions. It may also be desirable to add a portion of the sponge iron to the furnace with the initial charge.

The electrodes 24, 26 and 28 are lowered through their roof openings into proximity to the scrap contained in the furnace and a predetermined voltage applied to each electrode creating an arc which bridges the space between the electrodes and scrap thereby heating and melting the scrap in proximity to

the arc. As the scrap melts and falls away from the electrodes, an electrical control system causes the electrodes to be repositioned vertically an optimum distance from the scrap for maintenance or re-ignition of the arc, as necessary, and for maximum production of heat. The electrodes thus independently bore through the scrap melting the scrap in proximity thereto creating a cavity 60 having a molten metal pool 61 with a slag cover 70 therein below each electrode, the pools coalescing to form a generally trefoil-shaped pool centrally disposed within the furnace with a peripheral shell 71 of iron-bearing material forming a protective lining for the furnace wall, as shown in Figures 2 and 3.

The sponge iron charge 73 can be initiated at this stage, preferably into the area of the bath in proximity to and surrounding the arc flare zone by means of conduits 40, 42 and 44.

The rate of continuous charging of the sponge iron to the furnace is balanced with the power input and heat produced thereby to attain the desired tap temperature with concurrent achievement of the specified carbon content. For example, we have found that at a power input of 7.4 megawatts to a 25 ton furnace, a sponge iron pellet feed rate of 700 pounds per minute resulted in a 6°F. per minute fall in bath temperature and a feed rate of 500 pounds per minute resulted in a 7.5°F. per minute rise in bath temperature.

The carbon content in the initial charge should be sufficient to satisfy requirements for complete reaction with the oxide content of the sponge iron and ensure the desired carbon content in the finished steel. We have found that the reaction of the carbon with the oxygen available in the bath provides a vigorous boiling action which greatly facilitates melting of the sponge iron within the slag layer, improves heat transfer to the molten metal, and accelerates the refining of the steel.

In the charging of sponge iron to the pool or substantially open bath, we have also found that a thin slag layer having a controlled low viscosity can be maintained in the furnace for stabilizing the arc and permitting charging of sponge iron to the flare areas with immersion and rapid melting and coalescence of the sponge iron within the slag layer and transfer of the molten iron into the underlying molten iron or steel by gravity. Control of the slag viscosity is important in that a highly viscous slag impedes immersion of the sponge iron and retards melting and transfer of the molten sponge iron through the slag cover into the underlying molten metal. It is desirable to have slag cover of sufficient fluidity to enable the discrete charge material to penetrate the surface of the slag for melting and solutionizing therein aided by the carbon boil ias is discussed above, and to avoid the formation of a cover of sponge iron on the slag.

Typically, the slag analysis could be represented by the following range and example of a heat with slag within the range:

	Range (% by weight)	Typical Slag Example at Meltdown (% by weight)
SiO_2	2.0 — 40.0	32.84
Al_2O_3	0.0 — 20.0	6.28
CaO	1.0 — 50.0	17.40
MgO	0.0 — 25.0	23.84
P_2O_5	0.0 — 2.0	0.09
FeO	3.0 — 40.0	14.64
Other	—	4.91

The slag basicity ratio of typical heats is in the range 1.0 to 1.5. The basicity of the typical heat example given above was 1.1, *i.e.* ratio of "bases" to "acids" was 1.1.

Low basicity of the slag not only decreases the viscosity of the slag but also creates poor electrical conductivity conditions so that the arc tends to be buried within the slag layer. This permits high power to be used with less danger of overheating the side walls from an exposed arc.

The slag weight in a typical heat ranges from 100 to 125 pounds per net ton of steel. This is significantly lower than the approximately 150 pounds per ton of steel made from a charge of 100 per cent scrap.

The slag usually covers the metal bath to a depth of about 2 to 3 inches in order to

ensure penetration and melting of continuously fed pellets.

Surprisingly effective results have been attained by the methods of the invention as will be evident from the following general description and examples given hereinbelow carried out in two, three-phase electric-arc steel-making furnaces with nominal rated capacities of 15 and 25 tons, identified as furnace "A" and furnace "B" respectively, and powered in each case by an 8000 KVA transformer.

In general, according to the method of the invention, the furnace may be initially charged with sponge iron and steel scrap. Typical chemical compositions by weight of sponge iron pellets of the type disclosed are as follows:

CHEMICAL ANALYSES OF SPONGE IRON PELLETS BY % WEIGHT

	A	B	C	D	E	F	G
Total Fe	92.80	87.70	78.70	90.85	97.09	94.59	89.3
Metallic Fe	89.94	82.54	72.73	90.20	94.11	91.35	83.2
Iron Oxide	3.68	5.17	7.68	—	3.63	3.24	7.86
Oxygen in Iron Oxide	0.82	1.15	1.71	0.10	0.85	0.72	1.75
Carbon	0.098	0.409	0.125	0.15	0.194	0.42	0.19
Gangue							
Sulphur	0.008	0.051	0.014	0.008	0.029	0.010	0.042
Phosphorus	—	—	0.046	—	—	—	—
Titania	—	—	10.9	—	—	—	—
Lime	0.32	1.35	0.7	0.60	0.20	0.76	0.20
Magnesia	1.47	2.52	0.7	2.40	0.58	0.64	0.56
Silica	3.86	4.84	1.2	2.04	0.50	1.86	3.38
Alumina	0.60	1.87	5.4	0.96	0.56	1.00	0.17
Other Gangue	—	0.10	0.5	—	—	—	4.60
% Metallization	96.9	94.1	92.4	99.28	97.0	96.6	94.3

Percent Metallic Fe over percent total iron times 100 equals percent Metallization.

The scrap used consists of about 65 per cent mixed, unprepared material and about 35 per cent heavy melt material.

Carbon usually in the form of petroleum coke (due to its availability and low cost) is also added to the initial charge to provide carbon for the boil throughout the heat and to ensure sufficient carbon in the bath at the end of the heat.

This initial charge is partially melted using a circuit power in the furnace system of about 6.8 megawatts. When partial meltdown has been reached, controlled continuous pellet feeding is started. The initial feed rate in the various heats ranges from 300 to 500 pounds per minute. As the heat progresses, the feed rate is varied, as required, in order that the pellets will melt as soon as they make contact with, and penetrate the slag. If mounds of pellets, *i.e.* sponge iron covers, start to accumulate, the feed rate is slightly reduced in order to clear the mounds and regain the bath temperature. After approximately 2000 pounds of pellets have been charged, the transformer voltage settings are changed to produce a shorter arc with only a slight diminution in power.

The pellet feed is completed at this level of power input with variations in the feed rate being dependant upon the bath temperature, which is checked periodically with an immersion thermo-couple, to reach a bath tem-

perature near the tapping range for continuous casting of about 2950° to 3000°F. at the same time as pellet feeding is completed.

During a heat, metal bath samples are taken in order to follow the carbon drop of the melt, it being desirable to have the bath carbon within tapping range at the same time that the bath temperature approaches the tapping range. A final bath sample is taken after the pellet feed is completed.

No conventional refining period is required and the heats are thus able to be tapped as soon as the chemistry of the final sample is known. Because no sulphur or phosphorus problems generally are encountered with the iron-bearing materials used, it is possible to make the heats with no lime or limestone additions to the meltdown slag or remove the meltdown slag and replace it with a second slag.

Steels were made to the following specifications, with the intermediate 32 and 28 reinforcing bar grades predominating:

Grade of Steel	Range in Percentage by Weight of Steel				
	C	Si	Mn	S	P
Intermediate 32	0.30/0.34	0.15/0.30	0.45/0.85	0.050 Max	0.050 Max
Intermediate 28	0.28/0.32	0.15/0.30	0.45/0.65	0.050 „	0.050 „
A36 (ASTM Grade)	0.12/0.17	0.15/0.30	0.50/0.75	0.045 „	0.040 „

EXAMPLE 1

An initial charge consisting of 6,000 pounds of scrap and 12,400 pounds of sponge iron pellets of the composition described above as type "A" together with 400 pounds of petroleum coke were charge to the 15 ton "A" furnace. The electrodes were lowered and power applied for 24 minutes which resulted in the formation of a pool of molten metal therein. Sponge iron pellets, essentially spherical in shape and having a size range of from 5/8 to 3/16 inches, were then introduced through three conduits at locations near the arc flare zones at an average rate, when charging of 400 pounds per minute until a total of 14,000 pounds of pellets from continuous charging were in the furnace to make a total pellet charge of 26,400 pounds or 81.5 per cent of the metallic charge. Table I illustrates the time required for the steps of continuous charging, melting and refining the scrap, coke and sponge iron pellets.

TABLE I

Operating Step	Time Elapsed — Minutes
Power on	0
Initiation of controlled Pellet Charging	24
All Pellets Charged	69
Tap	84

Energy consumed was approximately 580 KWH/ton of steel tapped. A comparable heat time for melting and refining an all-scrap charge in the same furnace, according to conventional practice, was 161 minutes with an energy consumption of about 640 KWH/ton of steel tapped. The difference in power on to tap time represents a decrease time of 47.8 per cent in favour of the heat made with sponge iron pellets.

EXAMPLE 2

This example illustrates the operation of the invention wherein sponge iron chips, *i.e.* less than 3/16 inch, material having the composition described above as type "B", were fed continuously into the 25 ton "B" electric-arc furnace. An initial charge consisting of 10,000 pounds of steel scrap and 20,400 pounds of sponge iron chips and 430 pounds of petroleum coke were placed in the furnace. The electrodes were lowered and power applied for 32 minutes for the formation of a pool of molten metal before sponge iron chips were introduced via the special charging apparatus at an average rate of 500 pounds per minute until a total of 25,000 pounds of

sponge iron from continuous charging were in the furnace to make a total sponge iron charge of 45,400 pounds or 82 per cent of the metallic charge. Table II illustrates the time required for the steps of charging, melting and refining the scrap, coke and sponge iron.

TABLE II

Operating Step	Time Elapsed — Minutes
Power On	0
Initiation of Controlled Charging Chip	32
All Chips Charged	99
Tap	138

Energy consumed was approximately 560 KWH/ton of steel tapped. The production rate was 10.6 tons of steel produced per hour. Comparable energy consumption and productivity for melting and refining an all-scrap charge on the same "B" furnace according to conventional practice were 570 KWH/ton of steel tapped and 8.3 tons of steel produced per hour respectively. The productivity of the furnace was increased by about 28 per cent, through the use of controlled, continuous feeding of sponge iron chips. Productivity is defined as the production per unit of total furnace time.

EXAMPLE 3

This example illustrates the operation of the method of the invention wherein sponge iron of type "C" with high TiO_2 content and scrap of the type stated in Example 1 were fed to an open bath in the furnace. An initial 13,700 pound charge of scrap, 4,900 pound charge of the pellets and 400 pounds charge of coke were fed to the furnace. The electrodes were lowered and power applied for 26 minutes until the formation of the trefoil-shaped open bath before sponge iron pellets were introduced through three conduits at locations near the arc flare zones at an average rate of 420 pounds per minute until a total of 19,000 pounds of pellets from continuous charging were in the furnace to make a total pellet charge of 23,900 pounds or 63.5 per cent of the metallic charge. Table III illustrates the time required for the steps of charging, melting and refining the scrap, pig iron and sponge iron pellets.

TABLE III

Operating Step	Time — Minutes
Power to Electrodes	0
Initiation of Pellet Charge	26
All Pellets Charged	71
Tap	95

Energy consumed was approximately 712 KWH/ton of steel tapped. This is a very reasonable power consumption considering that this material contained a high gangue content; *i.e.* 19.5 per cent, and a combined oxygen content 1.71 per cent, well above the preferred range of 0.6 to 1.2 per cent.

A comparable heat time for melting and refining a similar type of scrap, as used in Example 3, according to conventional practice, was 171 minutes with an energy consumption of 652 KWH/ton of product. There exists a widespread opinion that titania-bearing materials are not amenable to steelmaking processing. However, we found that satisfactory slags could be produced according to the method of the present invention with optimum melting and refining of the sponge iron fed thereto at a reasonable energy consumption rate.

In the three foregoing examples a vigorous, steady boiling action took place in the bath throughout pellet feeding. This boiling action significantly improved heat transfer and permitted the sponge pellets to be readily en-

gulfed by slag, thereby increasing their rate of acceptance by the bath without the undesirable formation of floating mounds or clusters of unmelted material.

EXAMPLE 4

This example illustrates the operation of the method of the present invention at the lower residual oxygen content level of 0.1 per cent wherein sponge iron having the analysis of type "D" in the above table was fed into the "B" furnace. The initial charge consisted of 8,000 pounds of scrap, 200 pounds of coke and 12,935 pounds of pellets.

The electrodes were lowered and power applied for 27 minutes before starting to feed pellets into the arc flare zones. After the pellets were fed for a few minutes at a rate expected from previous tests to give the desired results, *i.e.* 450 pounds per minute, it was observed that the pellets tended to accumulate in mounds and the rate of pellet addition had to be decreased to 330 pounds per minute to balance the rate of feeding with the rate of melting of the pellets. With these highly metallized pellets no boil occurred in the bath and the solutioning of the pellets in the slag was retarded. The "no-boil" condition of the bath and pellet build-ups near the banks caused irregular eddy currents to be created in the bath. These in turn produced waves on the surface of the bath, causing the arcs to alternately extinguish and re-ignite frequently. The overall energy input was, therefore, lower than normal, making it necessary to further lower the rate of pellet feed to obtain the correct temperature rise. The heat time, 177 minutes, and power consumption, 635 KWH/ton of steel tapped, were comparable with that obtained in conventional practice.

It is evident, from Example 4 and to a lesser extent from Example 3, that there are limits to the amount of combined oxygen which can be tolerated in the sponge iron, if a completely controlled, continuous sponge iron pellet charging practice is to be acheved. Ecessive amounts of residual combined oxygen as iron oxide may lead to too violent bath action and too high a carbon consumption, thereby necessitating time consuming recarburizing operations in the refining period. On the other hand, the use of sponge containing insufficient amounts of residual combined oxygen (*i.e.* a highly metallized sponge) may produce a flat bath or "no boil" condition which hinders pellet solutioning in the slag layer. If highly metallized pellets are inadvertently produced, they can be used more effectively by a method of the present invention by feeding, simultaneously with the pellets, iron oxide, such as millscale or fine iron ore to make up the deficiency in combined oxygen in the highly metallized sponge iron pellets.

EXAMPLE 5

This example illustrates the operation of the present invention wherein sponge iron having the analysis of type "E" from the above table was fed into the "B" furnace. This sponge was in a granular form with 97% passing through a 10 mesh screen, *i.e.* having a particle size of minus 1/16 inch.

The initial charge consisted of 5800 pounds of scrap, 8500 pounds of pig iron and 11,100 pounds of sponge. Power was applied for 47 minuts and continuous feeding was initiated. Granular sponge was fed to the furnace at an average rate of 438 pounds per minute. During the feed periods, the slag tended to foam and rise to envelope completely the arcs. This foaming condition, probably due to iron oxide reduction within the slag layer (it being virtually impossible for the granular sponge to pass completely through the slag), produced the desirable result of effectively insulating the arcs and thereby eliminating refractory burning.

Table IV illustrates the time required for the steps of charging, melting and refining the scrap, coke and sponge iron.

TABLE IV

Operating Step	Time Elapsed — Minutes
Power On	0
Initiation of Controlled Spray Charging	47
All Sponge Charged	111
Tap	139

The energy consumed was approximately 540 KWH/ton of steel tapped, which was considerably below the average energy requirement of 570 KWH/ton for all-scrap heats made in the same 25 ton furnace. The lower energy consumption in the heat made with the granular sponge was due to the foamy slag which led to decreased heat losses from the metal bath. Steel productivity in the heat was 11.4 tons/hour or about 38 per cent

greater than the productivity of the average all-scrap heat of 8.3 tons/hour made in the same furnace.

EXAMPLE 6

An initial charge of 13,500 pounds of scrap, 4700 pounds of pig iron and 13,800 pounds of sponge iron pellets of the composition described above as type "F" was charged to "B" furnace. The electrodes were lowered and power applied for 24 minutes for formation of a bath of molten metal before a mixture of sponge iron pellets and chips of type "F" were introduced in the manner described above at an average rate of 383 pounds per minute until a total of 23,000 pounds of pellets and chips from continuous charging were introduced to make a total sponge iron charge of 36,800 pounds or 69 per cent of the metallic yield of 52,000 pounds. The sponge iron constituted 70 per cent pellets within the size range of from 5/8 inch to 3/16 inch and 30 per cent chips having a particle size smaller than 3/16 inch. Table V illustrates the time required for the steps of charging, melting and refining the scrap, pig iron and sponge iron pellets and chips.

TABLE V

Operating Step	Time — Minutes
Power to Electrodes	0
Initiation of Pellet Charge	24
All Pellets Charged	69
Tap	87

Energy consumption was approximately 555 KWH/ton of steel tapped at a power input of 7.1 megawatts; productivity being 10.4 tons/hour for an improvement in productivity of about 25.4 per cent relative to a comparable all-scrap heat of 8.3 tons/hour. A foamy slag about one foot thick was generated in each location of the continuous sponge feed effectively burying the electric arc to prevent refractory burning and improve heat transfer to the system. The melting rates with foamy slags induced by the continuous feed of fine sized sponge iron was about equal to the melting rates obtained by the feed of pellets but the energy consumption was enhanced. A series of trial runs indicated an energy consumption of 539 KWH/ton tapped, corrected to 525 KWN/ton, can be obtained with the controlled continuous feed of fine sized sponge iron.

The examples described hereinabove showing the reduced energy consumptions attainable with the present invention were conducted in 15 and 25 ton furnaces, "A" and "B", respectively. It will be evident that improved energy consumptions as low as 350 KWH/ton of product for cold charges and 250 KWH/ton of product with the use of hot metal or the preheating of the charge constituents may be attained with furnaces of increased capacity as compared with 400 KWH/ton for all scrap charges. For example, iron-bearing materials such as sponge iron in the form of pellets introduced into the furnace can be heated in a neutral atmosphere to a temperature below the melting point of the pellets prior to charging to accelerate melting of the charge within the furnace.

Figure 5 exemplifies a steelmaking system utilizing the method and apparatus of the present invention wherein melt furnace "A" is arranged in series with one or more refining furnaces "B" such that furnace "A" which receives scrap metal and a carbon-containng material such as petroleum coke produces a molten metal which can be transferred to furnaces "B" by ladles or the like conveying means. The hot metal forms an open bath in each of furnaces "B" and, after a suitable slag blanket or layer has been formed, the iron-bearing material such as sponge iron pellets is continuously fed to the slag blanket, preferably in proximity to the arc flare zone and partly surrounding it, for melting and refining as described hereinabove. The refined steel can be poured into moulds or into continuous casting units.

The present invention provides a number of important improvements in electric-arc steelmaking. By charging the furnace only once in the conventional manner, and by feeding the remainder of the metallic charge as sponge iron pellets through the roof into the area of the arc flare zones, a significant reduction in heat time is realized such that productivity of the furnace can be increased by more than 25 per cent with, in some tests, increases of up to 60 per cent being achieved.

The increase in productivity made possible by the controlled continuous charging method of the present invention, as illustrated in Figure 8 wherein productivies of the several iron-bearing materials treated in furnace "B", namely types B, D, E, F and G, are illustrated relative to their respective residual oxygen con-

tents and compared with conventional treatment of scrap, may be understood with reference to the schematic graphs shown in Figures 6 and 7 from which it will be evident that the use of the present invention for feeding sponge iron at a controlled, continuous rate during meltdown eliminates the need for making recharges of scrap to attain the desired final weight of metal. By this practice the loss in operating time which accrues during each recharge and also the loss of heat energy from the furnace when the roof is removed are avoided. The elimination of recharges is an important improvement in electric arc steelmaking, the rewards being shorter processing time with lower electrical energy consumption.

When the scrap has been melted sufficiently to provide trefoil pools of metal around the electrodes, and when controlled, continuous pellet charging is commenced at a rate where the pellets are taken quickly into solution in the slag and a regular, controlled boil therefore established, the arcs become stabilized and a higher power input can be achieved due to the uniform energy demand created by the steady stream of incoming sponge iron pellets. The difference in power input permitted in conventional scrap practice where erratic fluctuations in electric power input are a normal occurrence, Figure 6, compared with the method of the present practice where very steady high power input is possible, Figure 7, will also be evident.

An advantage of this improvement in electric-arc steelmaking is that with a higher and more uniform power input to the furnace the time required to melt the charge is shortened and the amount of circuit-breaker maintenance is decreased. A further advantage of smaller surges in power may be realized in those furnace locations where the electrical power companies object to the maximum swings in demand and insist upon additional reactance in the primary circuit to dampen these swings. In such localities the use of controlled, continuous sponge iron pellet feeding obviates such limitations to furnace power input. A further significant advantage from having a stabilized arc is the quieter operation which is of considerable importance to the melting shop personnel.

The life of the furnace refractories are enhanced when using controlled, continuous pellet charging. The curtain of falling sponge iron in proximity to and partly surrounding the arc, shown most clearly in Figures 2 and 3, effectively shields the walls and roof from the intense heat of the arc flare zones. Thus as long as sponge iron is being fed into the locations described herein, maximum power settings may be employed without fear of seriously damaging the furnace refractories. We have also found that the utilization of fine iron bearing material in the continuous charge, such as described in Examples 5 and 6, permits the controlled generation of a foamy slag which envelopes the arc for improved heat transfer and reduced energy consumptions at high power inputs while protecting the refractory lining from radiant heat damage.

In many areas where electric-arc furnace steelmaking shops are located, the quality of the scrap that is available is very poor; *i.e.* having an unknown and highly variable composition. In these areas, it is particularly desirable to have, in addition to the scrap as melting stock, sponge iron having a known composition with a low tramp element content. The use of the present invention has proven to be an effective way of utilizing sponge iron in amounts of up to at least 80 per cent of the charge without encountering the problems of cluster formation normally associated with sponge iron. This is an important advantage of the present invention.

Another important improvement in electric-arc steelmaking realized in using the present invention is the virtual elimination of the refining period. The high purity of the sponge iron pellets allows, as soon as all of the charge is melted, the production of steel having a sulphur and phosphorus content below the specified percentages for commercial steel grades. The controlled, continuous feeding of sponge iron pellets containing from 0.1 to 1.75 per cent residual oxygen combined with iron, preferably from 0.6 to 1.2 per cent, also allows the formation of a steady, active boil which removes carbon from the bath at a predictable and controllable rate so that at meltdown the bath of steel contains the desired or substantially desired carbon content. The steady, active boil also ensures that the non-metallic inclusions in the steel bath are brought to the surface and into the slag, giving rise to maximum steel cleanliness. The continuous feeding of sponge iron pellets is controlled at a rate that permits a steady rise of bath temperature such that the molten steel substantially reaches the desired tap temperature concurrent with completion of the feeding of the sponge iron pellets. A shortened, or substantially obviated, time for refining operations, *i.e.* removal of impurities and adjustment of the carbon content and bath temperature, therefore is achieved as is clearly indicated in Figure 7.

It will be understood that although the description of the methods of the present invention has proceeded with reference to "sponge iron", this term is intended to encompass discrete, free-flowing, iron-bearing materials in general, briquettes, granules, punchings, borings and fragmentized scrap which have a composition within the range of from 76 per cent to 99.5 per cent by weight total iron and residual oxygen combined with iron content of from 0.1 per cent to 1.75 per cent by weight.

Alloying and fluxing materials such as ferro-

manganese, ferrosilicon, lime and the like addition to that used in the initial charge can be added to the molten metal for refining of the metal within the furnace. The furnace can be adapted to discharge refined molten metal continuously to a casting unit wherein the quantity of metal tapped would be brought into phase with the quantity of iron-bearing material charged to the furnace.

The apparatus of the present invention can be arranged in conjunction with a rotary kiln for receiving hot sponge iron, carburized, if desired, directly from said kiln.

The present invention may also be used in the manufacture of grey cast iron and the like by recarburizing the bath after meltdown.

WHAT WE CLAIM IS:—

1. A method of producing steel containing from 0.02 to 1.8% carbon from materials containing metallic iron, in an electric arc furnace, comprising forming a metal pool with a layer of slag thereabove in the furnace, and then continuously introducing iron-bearing material in small particulate form, into the layer of slag above the metal pool at a rate controlled by reference to the electrical power consumption of the furnace such that at the end of the introduction of the iron-bearing material the metal melt is substantially at the temperature required for tapping the furnace and possesses the desired carbon content.

2. A method as claimed in Claim 1, wherein the iron-bearing material is introduced at a point adjacent the hot zones of the arcs in the region between the electrodes and the furnace wall.

3. A method as claimed in Claim 1 or Claim 2, wherein the iron-bearing material has a composition of from 76 per cent to 99.5 per cent by weight total iron with a residual oxygen content of from 0.1 per cent to 1.75 per cent by weight.

4. A method as claimed in Claim 3, wherein the iron-bearing material has a residual oxygen content of from 0.6 per cent to 1.2 per cent by weight.

5. A method as claimed in any preceding claim wherein the furnace is initially charged with scrap metal, fluxing, carbon and alloying additives.

6. A method as claimed in Claim 5, wherein the scrap metal has an initial carbon content higher than the carbon content of the refined steel.

7. A method as claimed in any preceding claim, wherein up to 80 per cent of the total metal charge to the furnace is in small particulate form, the total energy consumption of the furnace being from 250 to 700 KWH/ton of iron-bearing material.

8. A method as claimed in any preceding claim, wherein said particulate iron-bearing material is sponge iron which is produced in a rotary kiln and fed hot to the furnace.

9. A method as claimed in any preceding claim, wherein said particulate iron-bearing material is carburized sponge iron.

10. A method as claimed in any preceding claim, wherein said particulate iron-bearing material is TiO_2-bearing sponge iron.

11. A method as claimed in any of Claims 1 to 7, wherein said particulate iron-bearing material is fragmentized scrap with free-flowing mill scale or fine iron ore for providing a source of oxygen.

12. A method as claimed in any preceding claim, wherein at least 30% of said particulate iron-bearing material has a particle size of less than 3/16 inch.

13. A method as claimed in any preceding claim, wherein said particulate iron-bearing material has a particle size of less than 1/16 inch.

14. A method as claimed in any preceding claim, wherein carbon-bearing material is added to said furnace before tapping the molten steel for recarburizing the steel as grey cast iron.

15. A method as claimed in any preceding claim, wherein continuous feeding of the discrete particles particulate iron-bearing material is begun after initial charge melting is substantially complete.

16. A method of producing steel substantially as described herein with reference to the Examples.

17. Steel produced by the method as claimed in any preceding claim.

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Agents for the Applicants.

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Published by the Patent Office, 25 Southampton Buildings, London, W.C.2, from which copies may be obtained.

Fig. 1

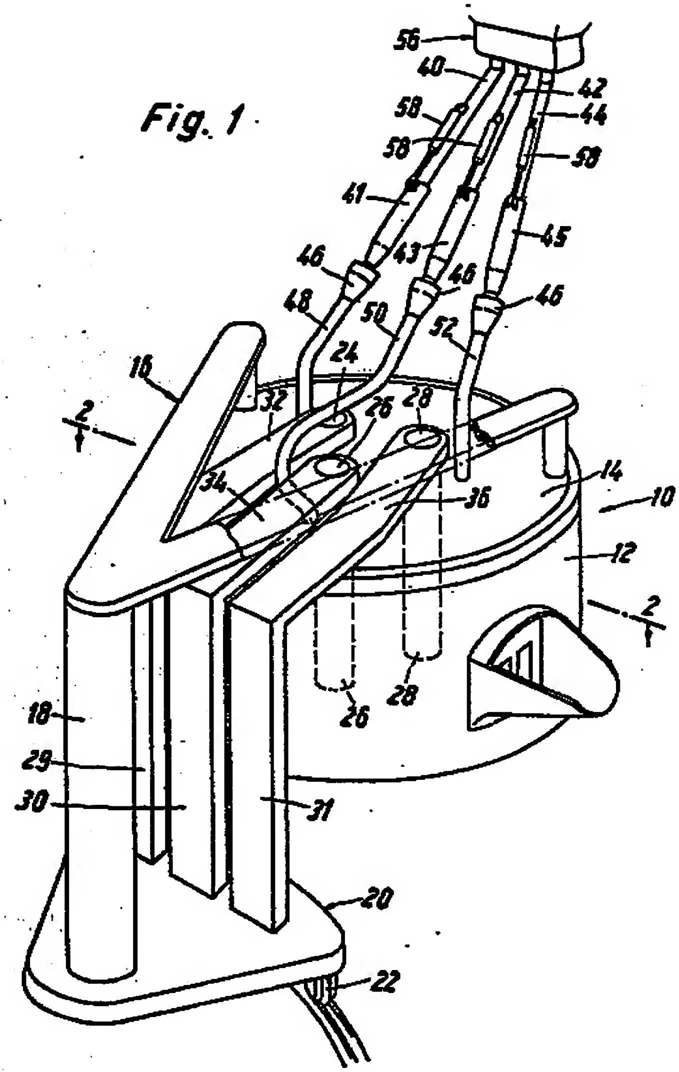

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Fig. 2

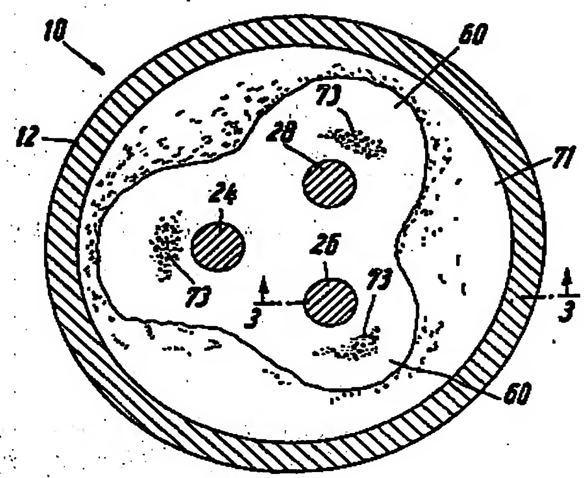
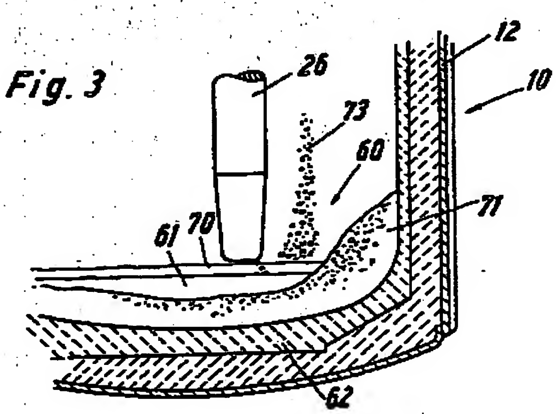


Fig. 3



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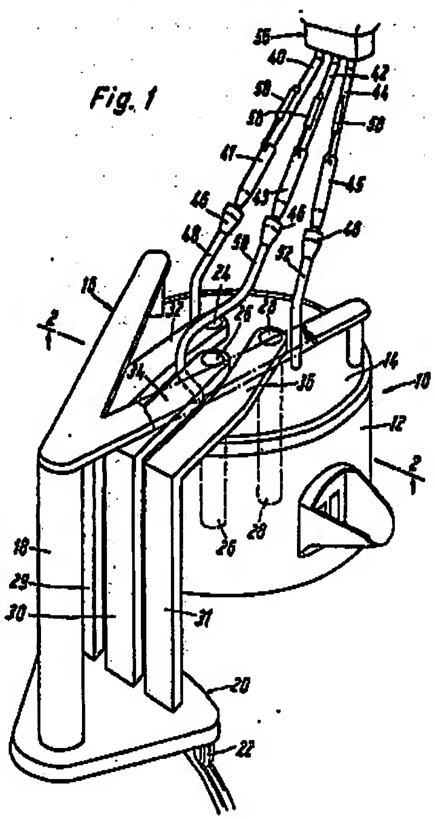

Fig. 1

Fig. 2

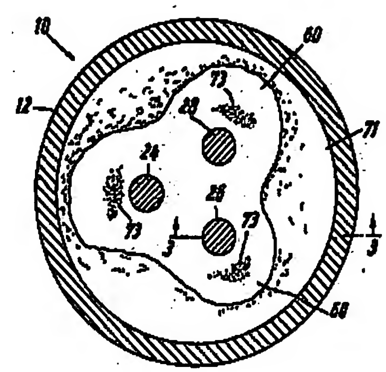

Fig. 3

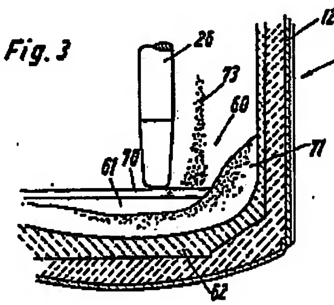

Fig. 4

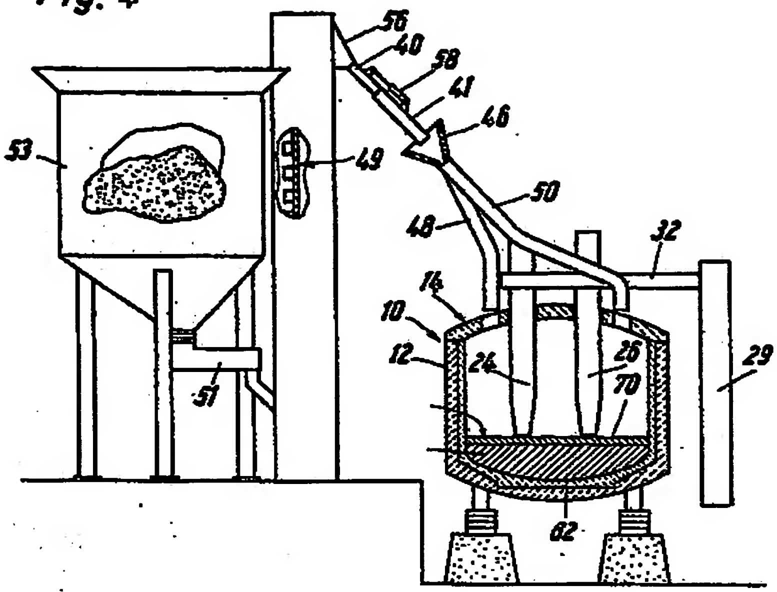

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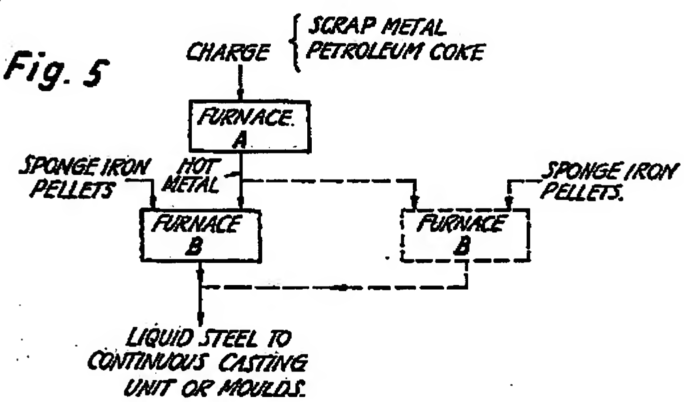
Fig. 5



CHARGE
SCRAP METAL
PETROLEUM COKE
FURNACE A
SPONGE IRON PELLETS
HOT METAL
FURNACE B
SPONGE IRON PELLETS.
FURNACE B
LIQUID STEEL TO CONTINUOUS CASTING UNIT OR MOULDS.

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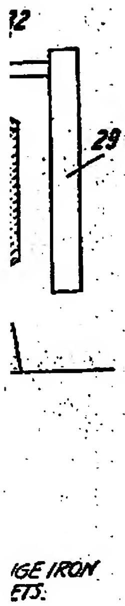
Sheets 3 & 4



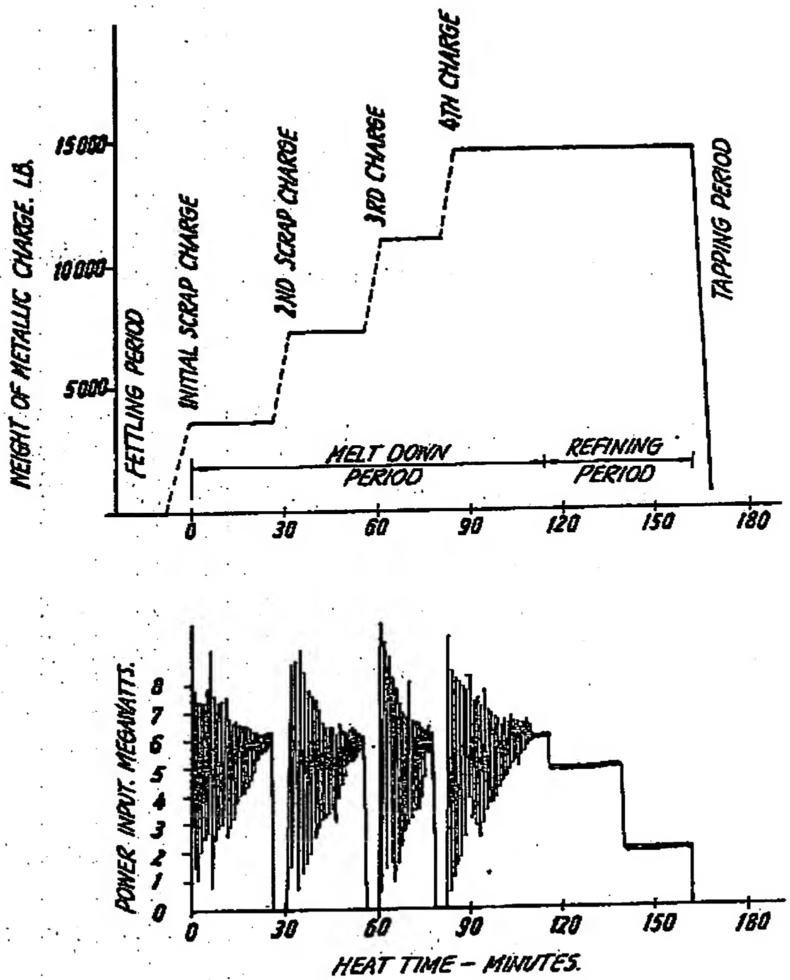


Fig. 6
PRIOR ART.

Fig. 4

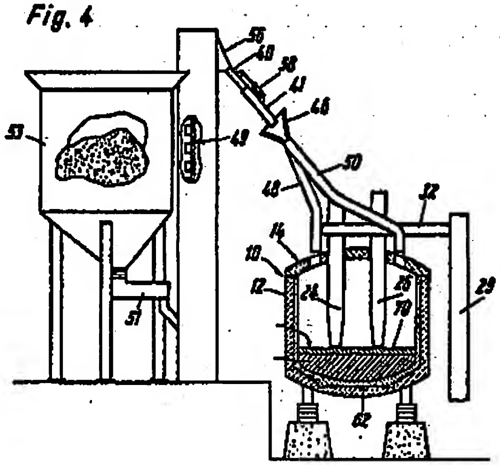
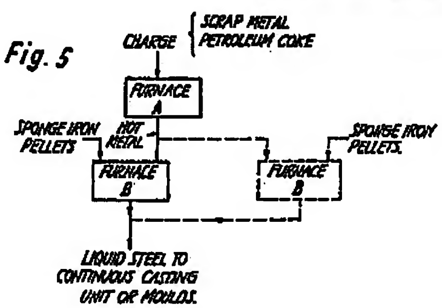


Fig. 5



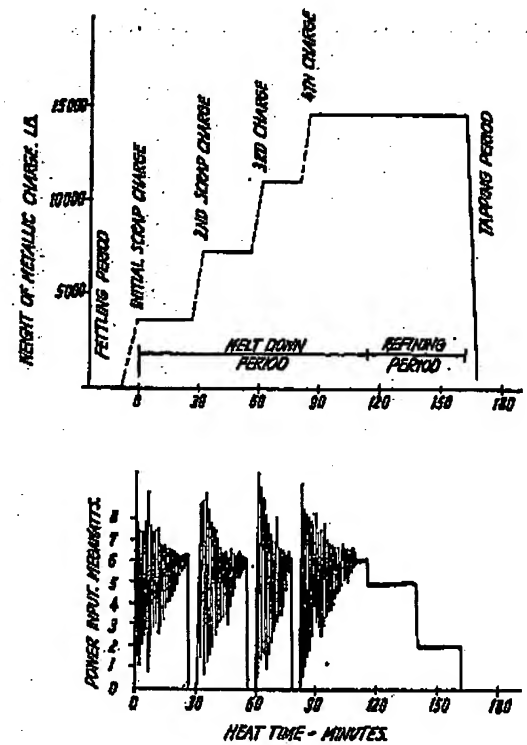
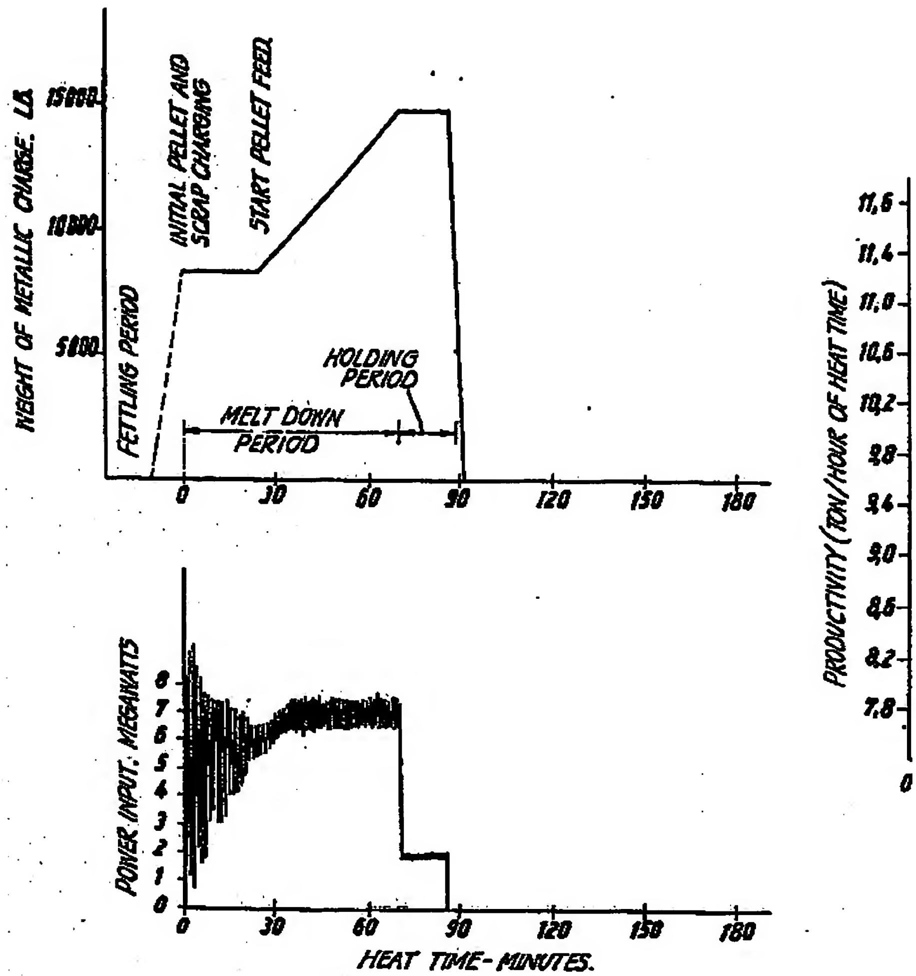


Fig. 6
PRIOR ART.


WEIGHT OF METALLIC CHARGE: LB.
15000
10000
5000
FETTLING PERIOD
INITIAL PELLET AND SCRAP CHARGING
START PELLET FEED
HOLDING PERIOD
MELT DOWN PERIOD
0
30
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90
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180
POWER INPUT: MEGAWATTS
8
7
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HEAT TIME-MINUTES.
PRODUCTIVITY (TON/HOUR OF HEAT TIME)
11,6
11,4
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8,2
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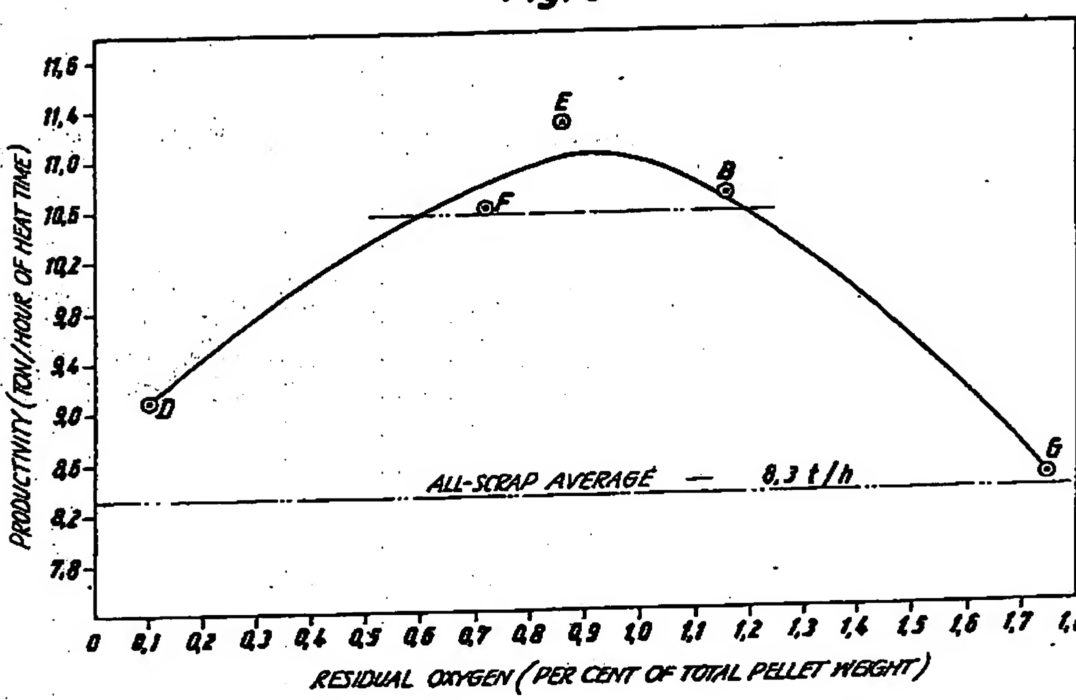
Fig. 7

Fig. 8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PRODUCTIVITY (TON/HOUR OF HEAT TIME)
E
B
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D
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ALL-SCRAP AVERAGE — 8,3 t/h
0
0,1
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RESIDUAL OXYGEN (PER CENT OF TOTAL PELLET WEIGHT)

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Sheet 5

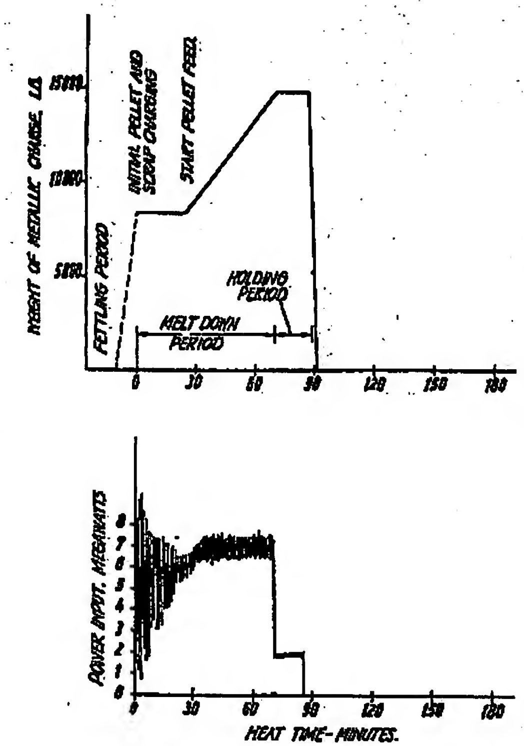
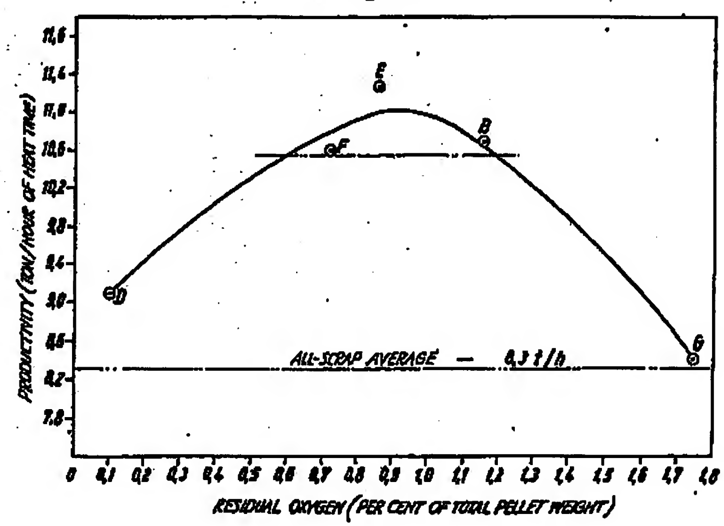


Fig. 7

Fig. 8



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